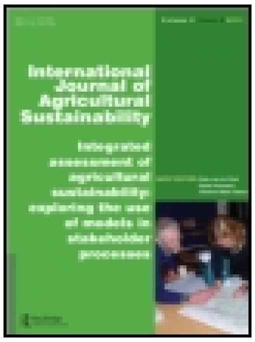

International Journal of Agricultural Sustainability

ISSN: 1473-5903 (Print) 1747-762X (Online) Journal homepage: https://www.tandfonline.com/loi/tags20

User-centred design of a digital advisory service: enhancing public agricultural extension for sustainable intensification in Tanzania

Berta Ortiz-Crespo, Jonathan Steinke, Carlos F. Quirós, Jeske van de Gevel, Happy Daudi, Majuto Gaspar Mgimiloko & Jacob van Etten

INTERNATIONAL JOURNAL OF AGRICULTURAL SUSTAINABILITY
https://doi.org/10.1080/14735903.2020.1720474

User-centred design of a digital advisory service: enhancing public agricultural extension for sustainable intensification in Tanzania

Berta Ortiz-Crespo [a], Jonathan Steinke[b], Carlos F. Quirós[b], Jeske van de Gevel [a], Happy Daudi[c], Majuto Gaspar Mgimiloko[c] and Jacob van Etten[b]

[a]Information Services and Seed Supplies, Bioversity International, Nairobi, Kenya; [b]Information Services and Seed Supplies, Bioversity International, Turrialba, Costa Rica; [c]Tanzania Agricultural Research Institute, Naliendele, Tanzania

ABSTRACT
Sustainable intensification (SI) is promoted as a rural development paradigm for sub-Saharan Africa. Achieving SI requires smallholder farmers to have access to information that is context-specific, increases their decision-making capacities, and adapts to changing environments. Current extension services often struggle to address these needs. New mobile phone-based services can help. In order to enhance the public extension service in Tanzania, we created a digital service that addresses smallholder farmers' different information needs for implementing SI. Using a co-design methodology – User-Centered Design – we elicited feedback from farmers and extension agents in Tanzania to create a new digital information service, called Ushauri. This automated hotline gives farmers access to a set of pre-recorded messages. Additionally, farmers can ask questions in a mailbox. Extension agents then listen to these questions through an online platform, where they record and send replies via automated push-calls. A test with 97 farmers in Tanzania showed that farmers actively engaged with the service to access agricultural advice. Extension agents were able to answer questions with reduced workload compared to conventional communication channels. This study illustrates how User-Centered Design can be used to develop information services for complex and resource-restricted smallholder farming contexts.

KEYWORDS
ICT; digital feedback; digital innovation; m-service; mobile phone

1. Introduction

To combat hunger and malnutrition, agricultural production needs to increase globally, and not least in many regions of sub-Saharan Africa (Godfray & Garnett, 2014). Yet agricultural expansion into natural ecosystems is not a reasonable option, as global land use change is already threatening vital ecosystem services, including carbon sequestration in savannahs, forests and wetlands (Rockström et al., 2017). Therefore, sustainable intensification (SI) has been proposed as a multi-objective paradigm, combining yield increases with long-term socio-economic and environmental improvements (Garnett et al., 2013; Loos et al., 2014; Pretty, 1997). SI represents a goal, rather than the pathway to achieve it, and requires different actions in different contexts (Ollenburger, Crane, Descheemaeker, & Giller, 2019; Petersen & Snapp, 2015). To achieve lasting adoption of SI practices by smallholders in sub-Saharan Africa, three main knowledge and information challenges need to be overcome. The first challenge is that farmers must be enabled to identify the right solutions for specific contexts (Godfray, 2015; Petersen & Snapp, 2015). The heterogeneity of farming systems, market opportunities, and agro-climate may require a diversity of changes at different spatial scales, as no single SI practice is viable everywhere (Sinclair & Coe, 2019); The second challenge is that many SI practices require farmers to acquire complex knowledge.

CONTACT Berta Ortiz-Crespo b.ortiz@cgiar.org

Simplistic recommendations may not be adequate for supporting successful SI adoption. For example, Integrated Pest Management requires farmers to recognize pests and their natural enemies, and to respond with different actions depending on the context (Pretty, 2018). A third challenge in ensuring adoption of SI is that farmers need to be empowered for lifelong learning and autonomous experimentation, to learn about new practices as well as to adapt and further develop introduced technologies. Therefore, they need constant access to diverse SI-related information, to support ongoing, flexible adaptation to changing pressures and opportunities (Brown, Nuberg, & Llewellyn, 2017; Pretty & Bharucha, 2014; van Etten et al., 2019).

Thus, the inherent characteristics of SI imply that farmers need information that is not only easily accessible, but also context-specific and open to feedback and iterative adjustment. Addressing these complex knowledge and information needs via conventional extension services is often challenging. Extension services often have insufficient financial resources and staff to carry out extensive field visits and demonstrations. Consequently, disseminated advice is rather generic and frequently does not reach households in remote areas (Feder, Anderson, Birner, & Deininger, 2010; Taylor & Bhasme, 2018). One opportunity has been information delivery via broadcast media (radio, television, DVDs). These media allow wide dissemination of agricultural contents without local presence of extension agents (Zoundji, Okry, Vodouhê, & Bentley, 2018). However, they offer limited opportunities for incorporating feedback from listeners. In addition, farmers are often required to tune in at set times. New digital services that use mobile phones have potential to address these limitations, since they enable on-demand access to content and support pluralistic, two-way information flows (Munthali et al., 2018). Mobile telephones benefit from a network coverage that is nearing ubiquity, and their penetration in sub-Saharan Africa is continuously growing (GSMA, 2019a).

Due to these opportunities, numerous digital services have been developed in recent years to improve smallholder farmers' access to agricultural information (Baumüller, 2018; Fabregas, Kremer, & Schilbach, 2019). Many existing solutions focus on supporting specific transactions along the value chain, such as providing market prices through SMS (Batchelor, Scott, Manfre, & Edwards, 2014). It has been noted, however, that many mobile information services make limited use of the possibility of two-way communication, reinforcing a top-down, one-size-fits-all approach in extension (Baumüller, 2018; Sulaiman V, Hall, Kalaivani, Dorai, & Reddy, 2012). A number of digital information services already integrate two-way communication and involve farmers in content creation (Haider Rizvi, 2011; Patel, Chittamuru, Jain, Dave, & Parikh, 2010). The challenge is to direct such efforts towards SI, which requires tailored advice.

In this paper, we explore how a digital information service can contribute more specifically to SI. This implies simultaneously addressing the three knowledge and information challenges mentioned above: the provision of agricultural advice that (a) caters for the heterogeneity of farming systems, (b) involves relatively complex agricultural practices, and (c) adapts to changing needs, to enable continuous innovation processes. The study took place in the context of the public extension system of Tanzania. To adjust the novel service to this context, the design process needed to avoid large gaps between design and reality, which have often limited the subsequent adoption of digital services by farmers (Dodson, Sterling, & Bennett, 2012; Heeks, 2002; Masiero, 2016). We implemented a user-centred design process, which helped to understand existing information needs, to select matching technologies, and to adapt them with feedback from prospective users. The objective of our study was to create a mobile information service that transforms how extension agents and farmers communicate with each other and that targets these three challenges. Here, we describe the design process, the new service and empirical insights from a first use phase.

2. Methods

2.1 Study area and context

We carried out research in Tanzania, where the government has launched several policies recognizing the importance of ICT tools for information dissemination and supporting the introduction of mobile phones for agriculture (URT, 2013, 2015). Our research took part in six districts of South-East Tanzania: Lindi DC, Masasi, Nachingwea, Nanyumbu, Ruangwa, and Tunduru (Figure 1). The study area has a tropical savannah climate. Agriculture is based on maize, cassava, pulses, and oil seeds (Perfect & Majule, 2010). Groundnuts are of high economic importance in the area, but many farmers lack knowledge on

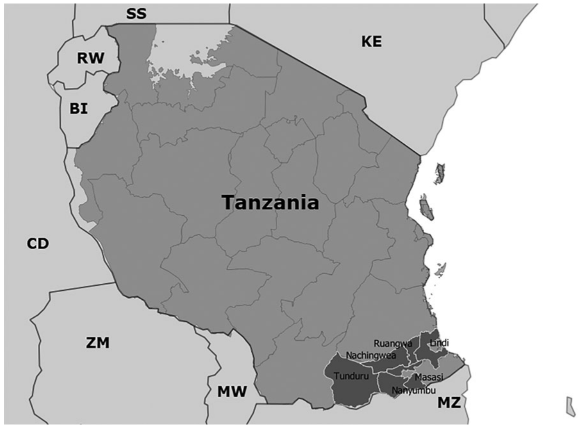

Figure 1. Research area. The six study districts are highlighted. Neighbouring countries are marked with ISO two-letter country codes. Data source: Humanitarian Data Exchange (HDX).

disease management (Daudi, Shimelis, Laing, Okori, & Mponda, 2018). In the study zone, crop yields are below the national average and poverty rates are above the national average (Perfect & Majule, 2010).

The design of the new information service focused on reducing aflatoxin contamination in groundnut production. Our work accompanied ongoing research efforts at the Tanzania Agricultural Research Institute-Naliendele (TARI-Naliendele) on this topic. Aflatoxins are produced by fungi of the genus *Aspergillus*, which can attack groundnuts at any moment during the planting cycle and post-harvest. Consuming contaminated produce can have health repercussions, including liver failure and stunted growth (Robens & Richard, 1992). Many import countries of groundnuts, including the European Union, have strictly regulated acceptable aflatoxin levels (Otsuki, Wilson, & Sewadeh, 2001). Thus, for farmers, controlling *Aspergillus* outbreaks through good agricultural practice implies increased nutritional and commercial value of production (Dorner, 2008). Improved household nutrition, increased agricultural income, and higher labour productivity are widely accepted goals of SI (Smith et al., 2017). Therefore, TARI-Naliendele promoted the recommended agronomic techniques by sensitizing farmers about the importance of aflatoxin prevention.

2.2 Design methodology

2.2.1. Overview

Our goal was to design and test a new information service that addresses the specific information and communication challenges of SI in smallholder context. To create this service, we adapted and applied a methodology of 'user-centered design' (Gulliksen et al., 2003). In user-centred design, preferences and needs of anticipated end-users of the product or service are analysed early in the process, in order to maximize usability. The future users of the service (e.g. farmers, extension agents) are involved in the design process, including in the specifying the problem, selecting partial solutions and providing inputs for refining a viable new tool or service through iterative trials. Following a five-step methodology, we moved from a broad problem and its context to a specific solution.

2.2.2. Step 1: context exploration

As a first step in the design process, we needed to understand existing constraints of farmers' access to agricultural information, in order to specify existing (partial) solutions and their limitations. To this end, we carried out interviews with 15 local smallholder farmers previously identified as having successfully implemented SI practices (Steinke et al., 2019a). These interviews served to understand how these farmers access agricultural information, highlighting which channels they prefer along with their respective limitations. In addition, we carried out two unstructured interviews with agricultural extension agents affiliated with TARI-Naliendele. The goal of these interviews was to understand the different types of information flows available to farmers, and their limitations as perceived by the agricultural extension agents.

2.2.3. Step 2: design criteria

Using insights from the interviews and drawing from the literature on SI, we defined several core requirements that needed to be addressed by the design of a new information service for SI (see Table 1).

2.2.4. Step 3: design decisions

In brainstorming sessions, we used the generated insights about available and preferred information channels and communication technologies to take several preliminary, interrelated design decisions. For each design criterion defined in step 2, we took a design decision, based on how a mobile phone-based solution could address it (see Section 3.1. below).

2.2.5. Step 4: prototype specification

Starting from the semi-specified design based on our design decisions, we combined different design options into alternative, coherent prototypes of the information service. These prototypical designs were tested with two groups of potential future users (6 women and men farmers, 8 extension agents) in two one-day workshops, which took place in December 2018 at the facilities of TARI-Naliendele. Simple 'mockups' that simulated the intended information service were created. We varied simulated characteristics across multiple tests and observed user behavior and reactions. We observed farmers' and extension agents' interactions with these mockups and recorded their usage behavior, including misunderstandings. We jointly discussed users' perceptions of the various prototypes and took decisions on the eventual design. Based on the decisions taken with farmers and agricultural extension agents, we eventually determined the characteristics of the service.

2.2.6. Step 5: pilot implementation and evaluation

We created a test version of the mobile information service and tested it with 97 farmers from the study area (among which 47 women) during a piloting phase of 28 days. Groundnut farmers were selected from communities previously involved in groundnut research activities by TARI-Naliendele. All test users received an initial training on the use of the new service. In one-day training events, TARI-Naliendele researchers presented the new service and registered participating farmers, using the 'ODK Collect' smartphone application (ODK, 2019). Every participant saved the phone number belonging to the service in their personal mobile phone. In addition, every farmer received an airtime voucher equivalent to approximately 35 min of using the service. After the pilot, we evaluated the usage data, including frequency and duration of calls, and options selected. Public extension agents in charge of the communities were approached and recruited for the pilot. Eight agents received training and a user manual in local language.

To evaluate the pilot, a household survey was conducted shortly after the pilot in the research region by TARI-Naliendele. This survey included 14 of the farmers who had used the service and 107 non-participants, both groups planting groundnuts in their fields.

Table 1. Design criteria for a new information service to support SI and public extension services.

Challenge	Design criterion	Explanation of criterion
Farmers need to identify the right solutions to their specific context, since farming systems, market opportunities and agro-climate are heterogeneous and there is not a single SI practice that is viable everywhere	Context specificity	The service should respond to diverse farming contexts, providing advisory messages adapted to different realities, from which farmers can chose.
Many SI practices require farmers to acquire complex knowledge in order to apply these practices properly in their farms.	Diverse perspectives	SI-related practices have highly context-dependent benefits and dis-benefits, so farmers need diverse views to take informed adoption decisions.
Farmers need constant access to diverse SI-related information to support flexible adaptation to changing pressures and opportunities.	Adaptability	The service should generate recurrent insights into changing and emerging knowledge and information needs, allowing the service to respond to these changes.
Extension services face a lack of economic and human resources which limits the farmers they can reach.	Resource efficiency	Compared to conventional advisory formats, the service should deliver more advisory messages per unit of time, making more effective use of available resources for extension services.
Current media offering agricultural content as TV and radio broadcast the information on specific times. Farmers reach extension agents through phone when there is some urgent, but the extension agent is not always available.	Constant availability	Farmers should be able to access information anywhere at any time, being able to apply the advice without delay in their farms. Also they should be able to communicate on time any issue, especially those that require fast action.
Extension agents cannot report easily their success to their supervisors.	Accountability	The platform should provide impartial data about extension delivery.

We used data from this survey to quantify the effects of having access to the service, in terms of adoption of new practices in groundnut farming. We defined six domains of farming in which innovations were promoted: field preparation, timing, pest management, disease management, harvesting, and post-harvest handling. For each domain, we asked farmers whether they had adopted new practices in the latest growing season. We tested for differences between the participants and non-participants, evaluating in how many domains they had adopted new practices. In addition, the 14 farmers were asked to evaluate the service using the 'system usability score' (SUS) (Brooke, 1996). SUS ranges from 0 to 100 and is measured on the basis of a standardized survey, where users indicate their agreement with ten statements on Likert scale.

3. Results

3.1 Design process

3.1.1. Step 1: context of agricultural information access

Interviews with farmers revealed the most important channels for receiving agricultural information along with their limitations. Firstly, agricultural TV and radio shows were widely popular. Given the lack of content schedules, however, farmers could not anticipate whether a TV or radio broadcast was relevant to them. Furthermore, the high labour burden of farming and associated activities meant it was challenging to fit the broadcasts with farmers' daily routines. Secondly, direct phone calls to agricultural extension agents were a widespread way to access relevant information. However, during peak agricultural season, extension staff was often overwhelmed with calls due to a high number of farmers per extension agent. At these times, it was hard for farmers to access information through phone calls. These insights about farmers' information-seeking preferences drove our design decisions that defined a preliminary service prototype, involving (a) pre-recorded 'radio-like' audio messages, (b) phone calls, and (c) on-demand access to advisory contents, to ensure that messages are relevant to farmers.

The interviews with extension agents highlighted the limitations they face in terms of low financial resources and staffing levels, which increase their workload and limit their ability to reach all farmers. Office tasks, such as reporting, reduce the time they can dedicate to farmers' issues, such as answering urgent questions or giving trainings. Extension agents also mentioned that they cannot easily report their successes to their supervisors.

3.1.2. Step 2: design criteria

To ensure the digital information service addresses the knowledge and information challenges imposed by SI, we defined three design criteria. Three additional criteria were defined to address observed limitations of the public extension service (Table 1).

3.1.3. Step 3: design decisions

For each of these design criteria, we took a design decision, specifying how a mobile phone-based information service could comply with the design criteria.

Context specificity: The service uses a hotline with interactive voice response (IVR) technology ('press 1 for topic X, press 2 for topic Y … '). IVR menus can be customized for different groups of users, e.g. to reflect different agro-ecological zones, differences in age or gender. Due to the small scale of our pilot, however, this user disaggregation was not implemented in practice.

Diverse perspectives: Information is delivered in the form of pre-recorded audio messages, which allows detailed explanations and integrates different, complementary sources of information, including specialized researchers and local, experienced farmers.

Adaptability: Through their phones, farmers can submit questions. At the online platform, extension agents attribute keywords to these. Analysing keywords and more in-depth qualitative analysis of the topics allows identifying needs for new, additional audio messages or required changes to existing audio messages.

Resource efficiency: Common questions are answered by the existing advisory audio messages, available through the IVR menu without further personal interaction with extension staff. Consequently, extension staff may dedicate resources, such as telephone calls and field visits, to more infrequent and unusual questions.

Constant availability: Information is provided via an automated hotline that gives access to pre-recorded messages and a mailbox. The service is available at any time.

Accountability: An online platform allows keeping track of the number of calls, choices made by callers in the IVR menu, duration of call, and numbers of questions made by farmers and answers provided by extension agent.

3.1.4. Step 4: prototyping sessions

Based on the design decisions, we developed various prototypes of the different components of an audio-based mobile agricultural information service. The prototypes included different layouts of the audio messages and the IVR menu. In participatory workshops with farmers and extension agents, the different prototypes of the service were jointly assessed and further specified through focus group discussions.

To discuss the design of audio messages, we listened to examples taken from the radio as well as examples recorded earlier with members of the local community. These sample messages varied in language (English/Swahili), narrators' background (farmer/agronomist/radio host), and length (between 2 and 10 min). It was decided that each audio message should include at least two different voices: an agronomist to provide accurate technical information, and an experienced farmer to explain practical aspects supported by experience. The agronomist should be from the local community or should represent a well-known, reputable institution. Messages should not exceed 5 min, to limit the risk of fatigue and distraction.

To determine the ideal design of the hierarchical IVR menu, we simulated two options by acting out the menu. A member of the research team 'played' the IVR, while a farmer/extension agent made choices. One of the alternative menus was narrow (two options per choice, but up to five choices before reaching a menu end node) while the other was shallow (maximum three choices, but up to seven options to choose from). This exercise revealed that the number of alternative options per IVR menu level should not exceed five.

As for contents, it was agreed that the service should provide information along the whole (groundnut) value chain. Pests and diseases should receive special attention, as information needs are most urgent in the light of ongoing pest attacks. Users stated the importance of recording contents in local language (Swahili). Extension agents emphasized the need for standardizing answers to farmers' questions, so that answers, once recorded, could be used in multiple instances.

3.2 Design product: Ushauri mobile advisory service

3.2.1. Overview

We created a functioning information service called Ushauri, the Swahili word for *advice*. The service consists of two integrated components (Figure 2): A mobile phone-mediated advisory service for farmers, and an online platform where agricultural extension agents manage their digital communication with farmers.

3.2.2. First service component: IVR advisory hotline for farmers

The Ushauri hotline grants farmers 24/7 access to a set of pre-recorded standard audio messages. Through touch tones, farmers use their mobile phones to navigate the IVR menu to select and listen to various pre-recorded agro-advisory messages (Figure 3). In addition, users may record further questions and comments in an automated mailbox. These recordings are then sent as audio files to the advisor's online dashboard, where they appear along with the name of the farmer who made the question (Figure 4).

The set of pre-recorded audio messages was created by TARI-Naliendele about the topics shown in Figure 3. These messages integrated inputs from agronomists, extension agents, and experienced local farmers. The length of these messages ranges from about 2 to 5:30 min (4 min on average). In the audio messages, an experienced farmer shares their experience with the respective topic, but also introduces themselves and leaves a phone number. This allows listening users to contact that expert farmer for further information exchange or arranging a visit.

Before being able to use Ushauri, each farmer needs to be registered by extension staff using the free 'ODK collect' smartphone application. Farmers are registered with their personal phone number to a local advisory group, which has one or more extension agents assigned. Registering each farmer to an advisory group allows assigning different IVR menus, with different sets of audio files, to different groups. This way, callers are individually identified and can be targeted with locally relevant information.

3.2.3. Second service component: online platform for agricultural extension agents

At the online platform, registered agricultural extension agents can listen to the recorded questions asked by the farmers assigned to them. Newly sent farmer questions are automatically highlighted (see orange 'Active' box in Figure 4). Extension agents can directly record answers, which are then sent as automated calls to the farmers who had asked the

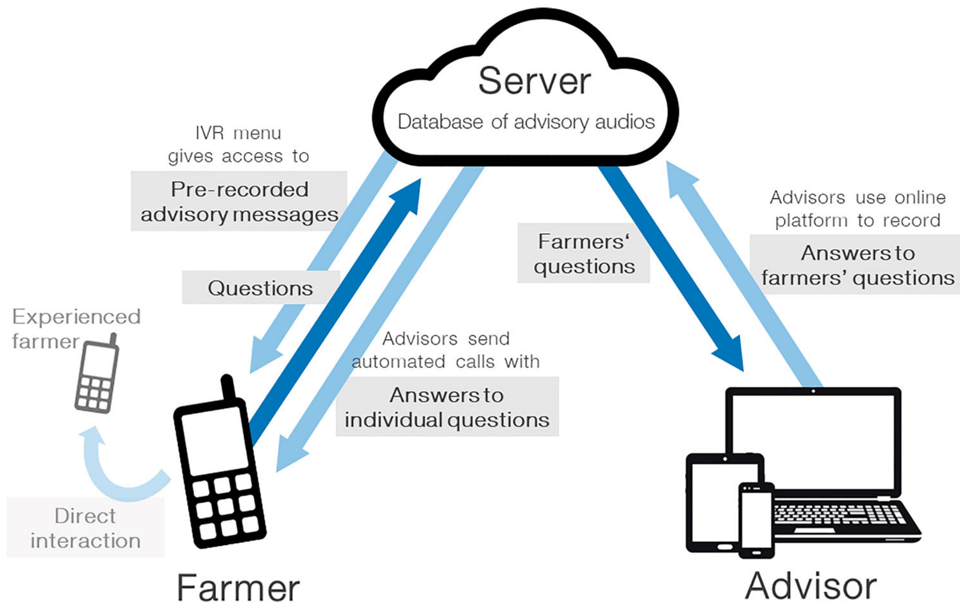

Figure 2. The integrated components of the Ushauri information service

questions. When a farmer misses the call, the dashboard will notify the extension agent, who can re-send the same audio message at any later moment (see pink 'Reply failed' box in Figure 4). Once a reply has been recorded, the platform allows extension agents to send the same message to multiple farmers who ask the same question at later moments. Furthermore, extension agents assign to each question one or more thematic key-words, for example, 'seed varieties'.

3.2.4. Roles of different user types

There are three main user types in the system: extension agents, farmers, and the system administrator. Each can perform different functions through one of three different digital tools: The online platform (accessible through computers or smartphones), the 'ODK Collect' application, and the IVR hotline (Table 2).

3.3. Pilot implementation

3.3.1. Service deployment

The hotline uses an automated call-in IVR system developed by Bioversity International through an international mobile phone provider called Twilio. We could not identify an affordable local VoIP provider in time for the field activities to start. Therefore, for piloting purposes, we used a Kenyan telephone number. This implied that farmers needed to make international calls, making the service more costly for Tanzanian users than if it had been offered via a local hotline number. In 2018 this service had a line maintenance cost of USD 20 per month. We also had to pay a rate for income calls of USD 0.10 per minute. The cost to the farmers was USD 0.28 per min, an usually high rate, due to the use of a Kenyan receiving number. We provided small incentives in the form of USD 10 airtime to stimulate farmers to call.

3.3.2. User experience

In first tests, it was found that the eight extension agents originally trained in using the system experienced insufficient mobile internet connectivity, which is needed for uploading answers. Therefore, two extension agents stationed at TARI-Naliendele (with fixed broadband internet access) were engaged for the pilot. The 14 farmers who had used Ushauri and were surveyed gave the service an average system usability score (SUS) of 80, which is between 'good' and 'excellent' (Brooke, 2013).

3.3.3. Overview of calls

Of the registered farmers, 84 (86%) decided to call Ushauri hotline at least once. The share of women

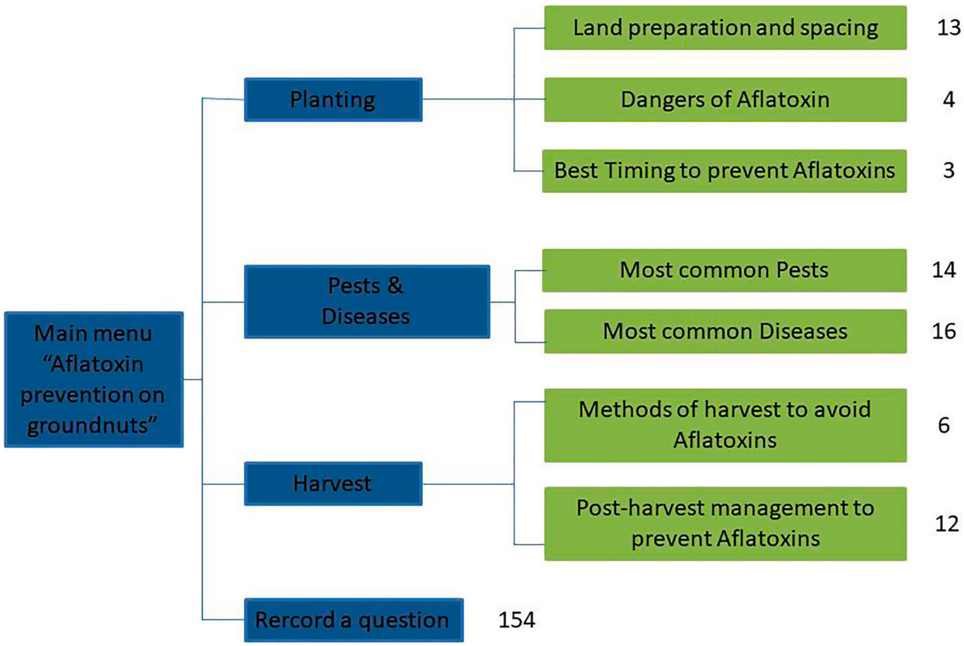

Figure 3. Call tree of the IVR menu implemented at the Ushauri hotline. The numbers denote the number of times each end node was accessed during the pilot phase.

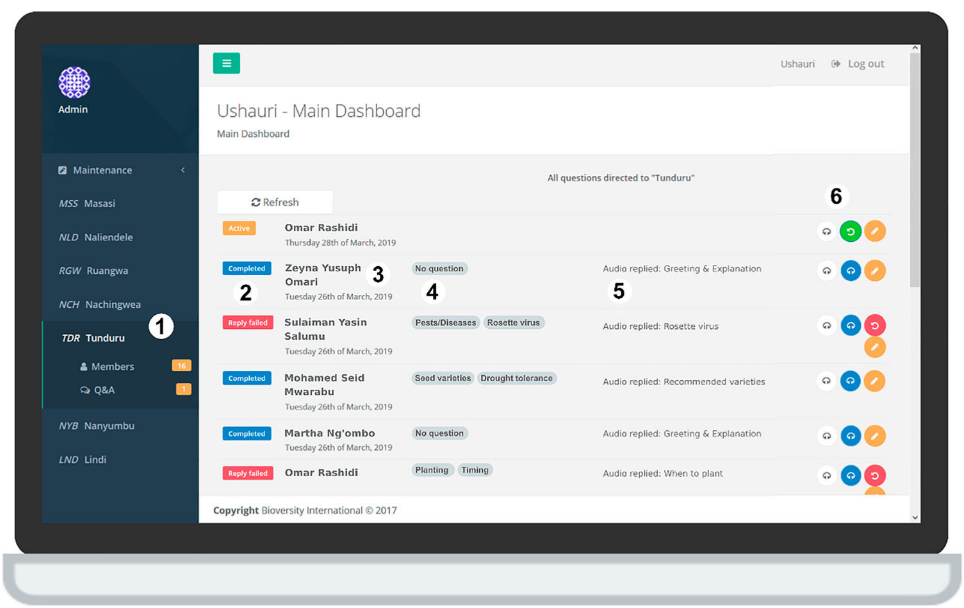

Figure 4. The question-and-answer dashboard at Ushauri.info. (1) Local advisory groups, (2) Question status, where 'active' (orange) is a new question, 'completed' (blue) means the reply was sent successfully, and 'reply failed' (pink) means the farmer did not pick up the phone, (3) Name of the farmer who made the question (Figure features fake names for illustration purpose) (4) Keywords added by the advisor to the question, (5) Name of the reply message sent to farmers, (6) Buttons for listening to the question (white), recording and sending a reply (green), listening to the reply sent by the advisor (blue), re-sending a failed reply (red), and adding/editing keywords (orange).

Table 2. Functions of the Ushauri system per user type.

User	Function	Medium	Description
Administrator	Create IVR menus	Online platform	Adding the voice prompts and audio messages that farmers for each group will access
Administrator	Create advisory groups	Online platform	Creating different groups for disaggregating advice, e.g. by region
Administrator	Register extension agents and assign them to groups	Online platform	Extension agents are in charge of replying to questions made by farmers. Each advisory group can have more than one advisor.
Administrator	Analyse usage data	Online platform	Access to usage statistics, e.g. number of calls, keywords added, etc.
Extension agent	Register farmers	ODK collect	Registering farmers to an existing local advisory group
Extension agent	Reply to questions	Online platform	Listening to the questions made by farmers and sending answers by recording a new message or selecting an existing answer
Extension agent	Add keywords	Online platform	Adding thematic keywords to the farmers' questions.
Extension agent	Create audios	Online platform	New audios can be recorded when a topic is highly demanded by the community
Farmer	Listen to audios	IVR call	Navigating through the IVR menu to select an audio advisory message
Farmer	Record questions	IVR call	Making any further question or suggestion
Farmer	Listen to answer	Automated push-call	Farmers receive an automated call when an answer is sent by their extension agent.

among active users represented their share in the total registered population. These users made a total of 389 calls. There were 14 calls per day on average, but 92% of the calls were made in the first two weeks (Figure 5).

Individual users made 4.6 calls on average. The duration of calls was unevenly distributed (median duration: 44 s), with 126 calls (33%) longer than 60 s. All in all, 219 individual calls (58%) successfully navigated the IVR menu to reach an end node, i.e. either listening to an agro-advisory audio message (65 calls) or recording a question (154 calls) (Figures 3 and 5). While the other 170 calls (42%) failed to navigate the IVR menu up to an end node, only two individual farmers *never* reached an end node. The share of failed calls (calls that did not reach an end node) remained constant over the course of the pilot (see Figure 5).

3.3.4. Farmers' questions

Of the 154 calls reaching the mailbox feature for recording questions, 49 were not real questions. These callers expected to be connected to a live operator. So, instead of making a question, the farmers hung up when nobody answered their greeting. To these users, the agricultural extension agents sent a standard message explaining the error and encouraging them to call again. Among the remaining 105 questions, 13 were repetitions, where individual farmers called more than once asking the same question. This means 92 individual farmer questions were made during the pilot. All records were listened to by one of the two assigned extension agents, using the *Ushauri.info* online dashboard on a laptop. The extension agents attributed keywords to the questions. Using these keywords, we clustered the questions by the major stages of the planting cycle (Table 3 and Figure 6).

3.3.5. Extension agents' answers

The agricultural extension agents answered all questions through the online platform. Because some questions were asked in similar form by different farmers, some answer recordings could be sent multiple times: For example, 19 farmers had asked about 'timing and land preparation', so the same answer, recorded once, was sent 19 times (see Table 3). All in all, answering the 92 questions required recording 33 replies. This means that each recorded answer was sent, on average, to 2.8 farmers. The advisor assigned to answer farmers' questions spent about one hour per day listening to questions and replying them, which in some cases involved doing literature research or asking colleagues for information. The mean waiting time for farmers to get an answer was 18 h (SD = 23 h). Standard deviation is high because some questions were made just before holidays and farmers had to wait until working days to get the answer. When the extension agent had to do background research, this also increased the waiting time of farmers.

3.3.6. Effects on adoption

The 14 farmers who had used Ushauri stated having implemented new practices in an average of 3.6

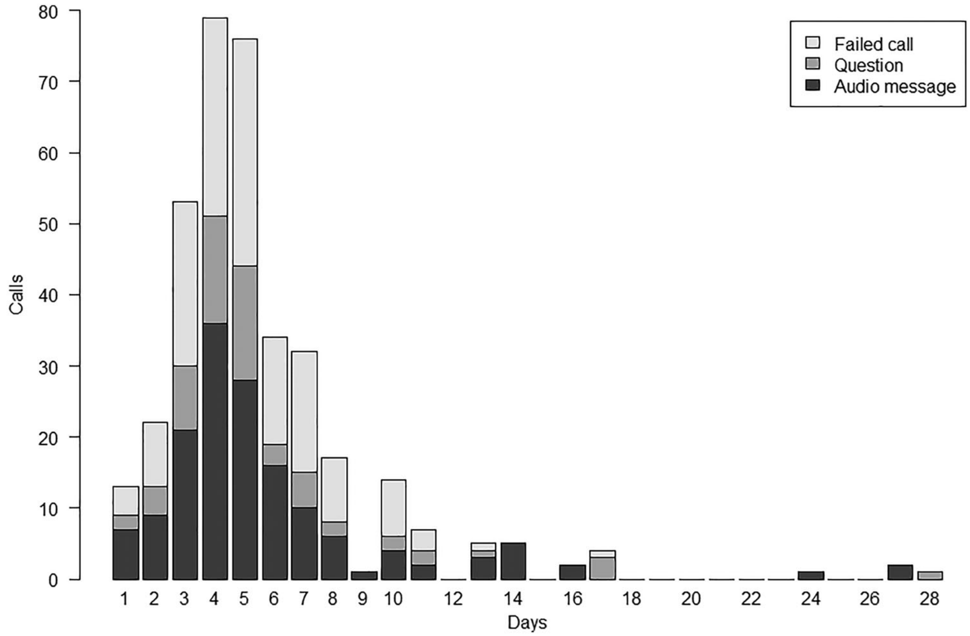

Figure 5. Number of audio messages listened, questions made by farmers and failed calls, per day.

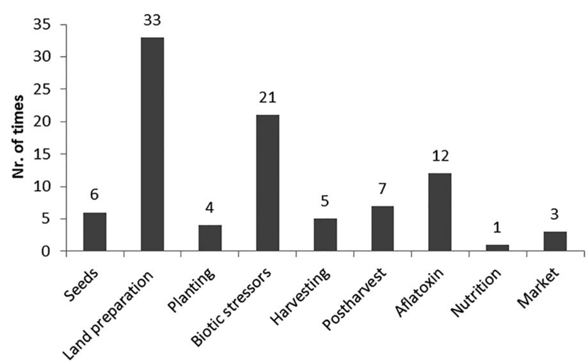

Figure 6. Number of questions by major stage in the growing cycle.

domains of groundnut production. This number was 1.2 for the 107 non-participants included in the survey, a significantly lower value (t-test, $p < 0.01$).

4. Discussion

4.1 Access to information on Sustainable Intensification

Our design and implementation of Ushauri, a mobile advisory service for small-scale farmers in Tanzania, explored how a user-centred design process can generate an information service for Sustainable Intensification in the context of public extension services that gets actively used by small-scale farmers. The platform has three specific features that address the Sustainable Intensification challenge.

Firstly, it intends to provide context-specific information. Since farmers need to be assigned to a specific advisory group on registration, along with other users that share certain characteristics (e.g. same agro-ecological zone), different user sub-groups can be targeted with alternative IVR menus containing different audio messages. Secondly, the service increases farmers' capacities to implement

Table 3. Overview of thematic keywords assigned to questions asked by farmers in the Ushauri hotline

Stage in the planting cycle	Keywords	Frequency (# times)
Seeds	Varieties	5
	Drought tolerance	1
Land preparation	Timing	19
	Recommended soil type	3
	How to prepare land	2
	Ploughing	2
	Recommended spacing	6
	Virgin land	1
Planting	Timing	2
	Fertilizers	1
	Weeding	1
Pests and diseases	Leaf spot	1
	Rust disease	1
	Rosette disease	4
	Rosette disease; insects	3
	Rosette disease; pesticide	3
	Rosette disease; seed size	1
	Ants; grubs	2
	Termites	2
	Aphids	1
	Drying leaves	2
Harvesting	Timing	2
	Maturity	2
	Yield potential	1
Post-harvest	Drying pods	4
	Storage	3
Aflatoxin	Detection	1
	Insect causing Aflatoxin	4
	Aflatoxin	1
	Health effects	3
	Control	1
	Pesticide; control	2
Nutrition	Consumption per year	1
Market	Price	3
Total		92

changes relevant to SI by integrating diverse perspectives on each topic. By including advice from both agronomists and experienced farmers from the community, Ushauri integrates formal and informal information sources, which has been shown to be crucial for successful agricultural transformation (Šūmane et al., 2018). This way, the service helps to make tacit knowledge explicit and supports its dissemination. Thirdly, the service can support adaptability to changing circumstances by the analysis of keywords added to farmers' questions. This analysis can reveal emerging information needs in the community. In our pilot implementation, for example, the large number of farmer questions around land preparation supports the need for recording an additional standard audio message about this topic, and adding it to the IVR hotline. Such adaptive development of the hotline can also be used to further improve context-specificity of the information provided via the hotline.

Ushauri can support an 'ecological knowledge system' by providing not only information, but also facilitating communication among farmers who might not otherwise be in contact (Kendall & Dearden, 2017; Röling & Jiggins, 1996). The service is a channel of exchange: Firstly, by actively involving farmers in the production of audio messages and providing their contacts for further communication outside the platform, thereby strengthening community interaction. And secondly, through the question-answering feature, which connects farmers with extension agents. This feature, however, could be further improved, for example, by letting farmers answer questions from fellow farmers (Patel et al., 2010). It needs to be tested whether or not, in our context, farmer-generated answers need a strong curation effort to ensure sufficient audio quality as well as relevant and technically correct contents.

Ushauri enabled farmers to access relevant information quickly. In many cases, this may be even faster than calling their local extension agents directly, who often cannot respond immediately. Through Ushauri, test users had immediate access to the pre-recorded messages, and received answers to their further questions within less than one day, on average.

4.2 Evidencing and improving extension performance

Our results suggest that the platform has the potential to significantly increase the efficiency of extension services. By storing farmers' questions in the online dashboard, Ushauri allowed extension agents to respond at a self-defined time of the day, reducing the level of phone call interruptions in daily work routine. Furthermore, it reduces the time required by extension agents to answer farmers' question through telephone calls. The fact that extension agents were able to send many recorded answers to more than one farmer implies an important gain in efficiency. The rate of message re-use could go up as the platform is used over longer periods. Compared to the alternative scenario of individual phone calls, this suggests that Ushauri can increase the number of farmers receiving answers, as many direct phone calls to the extension agent would have been left unanswered. Likewise, the potential reduction of extension agents' labour burden can free time that can be invested in creating new high-quality messages or addressing more complicated questions through background research.

The platform collects data potentially useful for auditing actual information delivery to smallholder farmers. For example, coverage rates (the proportions of farmers having access to extension) and number of extension contacts per season are relevant statistics. This is important because the quality of extension services is often only partially measured, limiting opportunities for performance management and accountability (Anderson & Feder, 2004). In our small-scale pilot, 84% of the farmers had a mean of 4.6 extension contacts in a month, which exceeded values found in literature (Abdulai, 2016; Krishnan & Patnam, 2014). Although our pilot, which was accompanied by a sensitization campaign and involved farmers with existing relations to the research centre, cannot be compared to a national or regional extension system, these insights suggest that digital advisory delivery can generate useful numbers for monitoring and evaluation of extension.

The early impact evaluation of Ushauri showed some effects on adoption of recommended practices. On average, users of Ushauri claimed to have implemented a higher number of new practices than non-users. It is not fully clear to which extent this difference can be credited to Ushauri, as social desirability bias may have led to exaggeration. In addition, the farmers had also received in-person trainings about aflatoxin prevention from TARI-Naliendele. In the future, more thorough randomized control trials should disaggregate adoption rates of in-person trained farmers vs. farmers using Ushauri, as well as considering long term effects.

4.3 Implications of the user-centred design process for the design product

The use of a user-oriented design methodology has helped to generate important insights that shaped the design product from the very beginning. For example, recognizing the popularity of both agricultural radio and phone calls among target users, through initial context exploration, narrowed down our design space. This avoided investing into prototyping around other available options, such as an SMS-based service, and thus likely contributed to increased service adoption by farmers. The employment of a participatory methodology is a promising strategy to avoid strong design-reality gaps in ICT4D projects (Masiero, 2016). During the prototyping workshops, important information about the perception and the usability of the service came up, such as the importance of integrating different perspectives within the same audio.

Our application of user-centred design was, however, not without limitations. During the prototyping sessions, users (farmers and extension agents) voiced only little criticism of the concepts suggested by the researchers, contributing mostly small modifications to the intended design. Research participants may have been biased by the (perceived) seniority of participating research staff. Avoiding 'insider-outsider tension', which frequently arises in participatory projects, requires (a) research partners with a close relationship to the participating communities; (b) the use of appropriate methodologies that allow the participants to express themselves openly, and (c) a substantial commitment in research time (Minkler, 2004).

With an average SUS of 80, farmers rated the system usability better than the average for IVR services, which is 73.8 (Bangor, Kortum, & Miller, 2008). Nevertheless, the SUS scores should be read carefully since there are some factors that could bias the results. A very important one is that the survey is officially formulated in English, and some terms and sentences can be difficult to understand for non-native English speakers (Finstad, 2006).

4.4 Insights from the pilot implementation

Most farmers called only during the early period of the pilot. There are several plausible explanations for this. Firstly, the unusually high cost of calling, may have refrained farmers from calling. Secondly, the number of audio messages offered through the hotline was low. Most farmers may have listened to their topics of interest already early into the pilot phase. Thirdly, farmers may have been interested mainly because of initial curiosity in the new technology rather than the content. For the future, it should be tested if updating call-in services with new contents on a regular basis would stimulate farmers' interest and increase call traffic.

Many callers hung up while navigating the IVR menu, without reaching an end node. Since the rate of such 'failed calls' did not decline over time, this suggests that other reasons, beyond farmers' initial inability to use the service, limited farmers' use of the service. Calls may have been interrupted by cuts in network connection or battery charge (Wyche & Steinfield, 2016). Also the farmer might have chosen to preserve costly airtime (see below). Call-in services should preserve farmers' potentially scarce resources by being accessible as fast as possible, for example by providing access to the decision tree via USSD, and at affordable prices or using toll-free numbers.

Before starting the pilot phase, extension agents had been trained on the utilization of the online platform for answering farmers' questions. During these sessions, it was noted that, despite owning a smartphone, some agents had difficulties using a browser and its different functions. The 'smartphone divide' among different types of users of this device has been described before (Park & Lee, 2015). This limitation needs to be considered by designers of future digital services, who should emphasize user-friendliness and intuitiveness in the design of online interfaces targeted at users who rarely surf the internet. During the trainings, we also experienced weak internet connectivity. This challenge may be overcome in the future. Mobile internet currently covers 70% of sub-Saharan Africa and this number is growing rapidly. Data bundles are getting cheaper to mobile users. The network speed available to farmers and extension agents is increasing as well, especially with the ongoing conversion from 3G to 4G (GSMA, 2019b). But to overcome the problem in the short term, some functions of Ushauri could be made available offline (e.g. recording an answer), and contents could be synchronized as soon as there is internet connectivity.

4.5 Challenges and opportunities for scaling

In this study, the service was tested in one region, providing advice about one crop and targeting a limited number of lightly trained farmers. A remaining question is how the service could be scaled up, providing advice about several crops, covering a large number of farmers and a larger geographical area. Providing advice about multiple crops may require the IVR menu to become more complex, which might increase attrition and increase the rate of failed calls. By requesting callers to answer a few initial questions about themselves through the IVR, the service could prioritize information in a household-specific way, and thereby limit the number of subsequent choices that callers need to make (Steinke et al., 2019b).

In our pilot, farmers were registered by extension agents. Reaching farmers that have little interaction with extension services, however, may require other ways of registering users, for example, through SMS or in agro-vet shops. Scaling to include different agro-ecological zones may require re-creating the same service multiple times, as advisory contents may differ. This could be facilitated by providing extension staff with script templates for the audio messages, where only location-specific details need to be changed in the recording process. Furthermore, if the number of targeted crops, users and geographical coverage grows, some central supervision is needed for updating the audios based on analysis of users' information needs.

While our proof-of-concept study was subsidized, out-scaling of an Ushauri-style information service might need sustainable funding to cover its cost. Costs are incurred for the creation of advisory audios, maintenance of the online platform, and sending push-calls to farmers. Staff time for answering farmers' questions is another cost, but as we show, the system could also provide savings in staff time. Cost recovery could involve new revenues from the private sector, for example through advertisement. On the other hand, costs could reduce, for example through bulk purchases of airtime by the government or special agreements between the government and telecommunication companies. The costs of phone calls may drop substantially with increasing volumes. For our pilot, it was not possible to establish an IVR hotline with a Tanzanian number. Instead, farmers called a Kenyan landline number, which cost an international call rate of USD 0.28/minute and may have discouraged farmers from calling. Under a more realistic scenario of a domestic hotline number – for example, calling the same number from within Kenya – can be as low as USD 0.006/minute. Even so, reaching the most marginalized parts of the farming population may still be challenging, as not all households have access to a mobile phone. Another concern is that poor households may not maintain credit in the phone throughout the entire year, or prioritize other uses of airtime over agricultural information access (Wyche & Steinfield, 2016). Offering the service via a toll-free number would allow maximum accessibility, but implies that the cost of farmers' calls needs to be borne by the extension provider.

The establishment of Ushauri at national level would require governmental support. Tanzania has included the increased use of ICT within its national policy objectives for the agricultural sector (URT, 2013). The country's current long-term agricultural development strategy, however, does not designate any specific actions to promote and facilitate digital development (URT, 2015). Recent experiences with promising digital solutions for public agricultural extension in Tanzania have, thus, highlighted several policy needs: Up-scaling successful pilots has been challenging due to the need for training extension agents in ICT usage and the widespread lack of modern devices and stable internet connectivity and electricity at extension centres. The high cost of necessary investments in infrastructure and devices have so far hindered greater policy-maker support for establishing new communication procedures in agricultural extension (Barakabitze et al., 2015; Mlozi et al., 2016).

4.6 Remaining research needs

The results presented in this paper correspond to the first design iteration of Ushauri. Furnished with the insights generated during this research period, the platform can be refined and improved. In the future, a running service could be used to further optimize the different components of the audio messages, such as length, combination of voices, structure, language and topics. This could be done by creating different versions of the service and its components, and monitoring user interactions (A/B testing). Further attention should be given to studying farmers' and extension agents' user experiences with the platform, since Ushauri relies on their ability and will to interact with an online platform. Future iterations of the platform could consider enhancing its design to make it as inclusive and intuitive as possible for farmers and extension agents. Evaluating the impacts of Ushauri-style information services will require determining to what extent farmers implement the received advice on their farms. Information on implemented practices can be collected from farmers directly through the IVR interface (Eitzinger et al., 2019).

5. Conclusion

Our study shows that, firstly, a mobile advisory service, created through a user-centred design process, can help to address the communication and information challenges of Sustainable Intensification. During the pilot, a high share of farmers actively used the service, demonstrating its potential to improve farmers' access to agricultural information. Secondly, the service supports adaptive management and iterative improvement of the provided advice, as the standard contents can be recurrently modified and completed in response to farmers' questions. This addresses the need for an evolving, adaptive knowledge service, which is crucial to the SI paradigm. Thirdly, the study shows how this type of service can enhance the effectiveness of extension. By answering similar questions, from different farmers, with the same answer message, extension agents were able to reduce their workload. This demonstrates that advisor-farmer communication through voice messages can increase the efficiency of advisory services, allowing extension staff to answer a higher number of farmers' questions than through conventional communication channels (phone calls). Lastly, the study shows how the use of Ushauri generates performance metrics that can inform decision-makers on the performance of the extension service. The use of a participatory methodology helped to craft a service that fits local contexts, including the specific communication challenges and opportunities. Engaging with the public extension service throughout the design process fostered ownership, which provides opportunities for future uptake and institutional embedding of the service.

Acknowledgements

We thank Olga Spellman and Vincent Johnson (Bioversity International) for language editing support. The views expressed in this paper are those of the authors and do not necessarily reflect the UK government's official policies.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This study has been funded by UK aid from the UK government.

Notes on contributors

Berta Ortiz-Crespo holds a bachelor in Biology from University of Valencia (Spain) and a MSc in Integrated Natural ResourceManagement from Humboldt University of Berlin (Germany). She joined Bioversity International and the team information services and seedsupplies to write her master thesis "Designing a mobile phone-based two-ways information system for agricultural advisory services inEastern Africa". She's currently working as a consultant on the design and implementation of ICT solutions for agriculture, leading projectswith local partners in Kenya, Tanzania and Ethiopia.

Jonathan Steinke is an agricultural development researcher with Bioversity Internationaland Humboldt-Universität zu Berlin. His research focuses on facilitating farmer participation in agricultural research and extension throughnovel mass-participatory methodologies, such as citizen science, and the use of modern communication media, such as mobile phones. Hehas worked on smallholder livelihood diversity and climate adaptation in Central America and Eastern Africa and is currently based in Berlin,Germany.

Carlos Quiros has twenty four years of experience in ICT in different capacities ranging from technical to managerial with overthirteen years supporting international agricultural research and development. Active involvement with ICT4D in numerous successfullyimplemented multi-country projects in Africa, Asia and Latin America. Currently working for Bioversity International.

Jeske van de Gevel is aresearch fellow, holds a MSc degree in the Management of Agro-Ecological Knowledge & Social Change from Wageningen University, a BScdegree in Forestry and Nature Conservation of Larenstein University of Professional Education. She specialises in participatory researchand agricultural innovation, citizen science and design-based research. She has been working with the Alliance of Bioversity International andCIAT, a CGIAR research institute, since 2012, and in addition, joined the University of York in 2017 as a PhD researcher.

Happy Daudi is anAgriculture Research Officer, holds MSc degree in Plant breeding and a PhD student in Plant breeding at KwaZul Natal University in SouthAfrica. She has a significant experience in working with farmers especially in Groundnut and sesame crop. She is based in Tanzania. She isactively involved in different projects related to breeding of groundnut crop and improving livelihood of small holder farmers inTanzania.

Majuto Gaspar Mgimiloko is an agricultural researcher Tanzania Agricultural Research Institute (TARI) - Naliendele in Mtwara -Tanzania. Working in technology transfer and partnerships. He has worked with Local Government (LGA) in Agriculture Sector at NewalaDistrict in Tanzania and is currently based in Mtwara, Tanzania.

Jacob van Etten is the Research Director for the Digital Inclusion Lever of theAlliance of Bioversity International and CIAT. Jacob is an interdisciplinary agricultural scientist with expertise in social, environmental and plantsciences. He joined Bioversity International in 2012 as a research team leader, working on climate adaptation and citizen science. His researchfocus is on new digital solutions for agricultural development that have a user-centric approach to ensure solutions respond to the needsand challenges of prospective users. Before joining Bioversity, he worked for the Food and Agriculture Organization of the United Nations(FAO) in Mali, the International Rice Research Institute (IRRI) in the Philippines, and IE University in Spain.

ORCID

Berta Ortiz-Crespo http://orcid.org/0000-0002-6664-0815
Jeske van de Gevel http://orcid.org/0000-0002-9637-9099

References

Abdulai, A. N. (2016). Impact of conservation agriculture technology on household welfare in Zambia. *Agricultural Economics*, *47*, 729–741.

Anderson, J. R., & Feder, G. (2004). Agricultural extension: Good intentions and hard realities. *The World Bank Research Observer*, *19*(1), 41–60.

Bangor, A., Kortum, P. T., & Miller, J. T. (2008). An empirical evaluation of the system usability scale. *International Journal of Human-Computer Interaction*, *24*(6), 574–594.

Barakabitze, A., Kitindi, E., Sanga, C., Shabani, A., Philip, J., & Kibirige, G. (2015). New technologies for disseminating and communicating agriculture knowledge and information: Challenges for agricultural research institutes in Tanzania. *The Electronic Journal of Information Systems in Developing Countries*, *70*(2), 1–22.

Batchelor, S., Scott, N., Manfre, C., & Edwards, D. (2014). Is there a role for mobiles to support sustainable agriculture in Africa? *2nd International conference on ICT for sustainability (ICT4S)* (pp. 272–280). Stockholm, Sweden.

Baumüller, H. (2018). The little we know: An exploratory literature review on the utility of mobile phone-enabled services for smallholder farmers. *Journal of International Development*, *30* (1), 134–154.

Brooke, J. (1996). SUS – a quick and dirty usability scale. Usability evaluation in Industry. In P. W. Jordan, B. Thomas, B. A. Weerdmeester, & I. L. McClelland (Eds.), *Usability evaluation in industry* (pp. 189–194). London: Taylor & Francis.

Brooke, J. (2013). SUS: A retrospective. *Journal of Usability Studies*, *8*(2), 29–40.

Brown, B., Nuberg, I., & Llewellyn, R. (2017). Stepwise frameworks for understanding the utilisation of conservation agriculture in Africa. *Agricultural Systems*, *153*, 11–22.

Daudi, H., Shimelis, H., Laing, M., Okori, P., & Mponda, O. (2018). Groundnut production constraints, farming systems, and farmer-preferred traits in Tanzania. *Journal of Crop Improvement*, *32*(6), 812–828.

Dodson, L., Sterling, S. R., & Bennett, J. K. (2012). Considering failure: Eight years of ITID research. *Information Technologies and International Development*, *9*(2), 19–34.

Dorner, J. W. (2008). Management and prevention of mycotoxins in peanuts. *Food Additives and Contaminants*, *25*(2), 203–208.

Eitzinger, A., Cock, J., Atzmanstorfer, K., Binder, C. R., Läderach, P., Bonilla-Findji, O., … Jarvis, A. (2019). Geofarmer: A monitoring and feedback system for agricultural development projects. *Computers and Electronics in Agriculture*, *158*, 109–121.

Fabregas, R., Kremer, M., & Schilbach, F. (2019). Realizing the potential of digital development: The case of agricultural advice. *Science*, *366*, 6471. eaay3038.

Feder, G., Anderson, J. R., Birner, R., & Deininger, K. (2010). *Promises and realities of community-based agricultural extension*, IFPRI Discussion Paper No. 959. Washington D.C: International Food Policy Research Institute.

Finstad, K. (2006). The system usability scale and non-native English speakers. *Journal of Usability Studies*, *1*(4), 185–188.

Garnett, T., Appleby, M. C., Balmford, A., Bateman, I. J., Benton, T. G., Bloomer, P., … Godfray, H. C. J. (2013). Sustainable intensification in agriculture: Premises and policies. *Science*, *341*(6141), 33–35.

Godfray, H. C. J. (2015). The debate over sustainable intensification. *Food Security*, *7*(2), 199–208.

Godfray, H. C. J., & Garnett, T. (2014). Food security and sustainable intensification. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *369*(1639), 20120273.

GSMA. (2019a). *Connected society*. The state of mobile internet connectivity 2019. Retrieved from http://www.comscore.com/Press_Events/Press_Releases/2010/6/comScore_Reports_April_2010_U.S._Mobile_Subscriber_Market_Share.

GSMA. (2019b). *The mobile economy Sub-Saharan Africa 2019*. Retrieved from https://www.gsma.com/r/mobileeconomy/sub-saharan-africa/.

Gulliksen, J., Göransson, B., Boivie, I., Blomkvist, S., Persson, J., & Cajander, A. (2003). Key principles for user-centred systems design. *Behaviour & Information Technology*, *22*(6), 397–409.

Haider Rizvi, S. M. (2011). Lifelines: Livelihood solutions through mobile technology in India. In D. J. Grimshaw & S. Kala (Eds.), *Strengthening rural livelihoods: The impact of information and communication technologies in Asia* (pp. 53–70). Ottawa: Practical Action Publishing and International Development Research Centre, Rugby.

Heeks, R. (2002). Information systems and developing countries: Failure, success, and local improvisations. *The Information Society*, *18*, 101–112.

Kendall, L., & Dearden, A. (2017). ICTs for agroecology. In *International Conference on Social Implications of Computers in Developing Countries (ICT4D 2017)* (pp. 451–462), Yogyakarta, Indonesia.

Krishnan, P., & Patnam, M. (2014). Neighbors and extension agents in Ethiopia: Who matters more for technology adoption? *American Journal of Agricultural Economics*, *96*, 308–327.

Loos, J., Abson, D. J., Chappell, M. J., Hanspach, J., Mikulcak, F., Tichit, M., & Fischer, J. (2014). Putting meaning back into “sustainable Intensification”. *Frontiers in Ecology and the Environment*, *12*(6), 356–361.

Masiero, S. (2016). The origins of failure: Seeking the causes of design–reality gaps. *Information Technology for Development*, *22*(3), 487–502.

Minkler, M. (2004). Ethical challenges for the “outside” researcher in community-based participatory research. *Health Education & Behavior*, *31*(6), 684–697.

Mlozi, M. R. S., Sanga, C., Tumbo, S., Mussa, M., Kadeghe, F., & Haug, R. (2016). *Delivery of agricultural extension service can be improved through mobile phones*. EPINAV Policy Brief 2/2016.

Munthali, N., Leeuwis, C., van Paassen, A., Lie, R., Asare, R., van Lammeren, R., & Schut, M. (2018). Innovation intermediation in a digital age: Comparing public and private new-ICT platforms for agricultural extension in Ghana. *NJAS - Wageningen Journal of Life Sciences*, *86*, 64–76.

ODK. (2019). *Open data kit documentation*. Retrieved from https://docs.opendatakit.org/_downloads/ODK-Documentation.pdf.

Ollenburger, B. M., Crane, T., Descheemaeker, K., & Giller, K. E. (2019). Are farmers searching for an African green revolution? Exploring the solution space for agricultural intensification in Southern Mali. *Experimental Agriculture*, *55*(2), 288–310.

Otsuki, T., Wilson, J. S., & Sewadeh, M. (2001). What price precaution? European harmonisation of aflatoxin regulations and African groundnut exports. *European Review of Agricultural Economics*, *28*(3), 263–284.

Park, E., & Lee, S. (2015). Multidimensionality: Redefining the digital divide in the smartphone era. *Info*, *17*(2), 80–96.

Patel, N., Chittamuru, D., Jain, A., Dave, P., & Parikh, T. S. (2010). Avaaj Otalo – A field study of an interactive voice forum for small farmers in rural India. *Proceedings of the CHI conference on human factors in computing systems, Atlanta, USA* (733–742).

Perfect, J., & Majule, A. E. (2010). *Livelihood zones analysis. A tool for planning agricultural water management investments*. Tanzania: International Water Management Institute (IWMI).

Petersen, B., & Snapp, S. (2015). What is sustainable intensification? Views from experts. *Land Use Policy*, *46*, 1–10.

Pretty, J. (2018). Intensification for redesigned and sustainable agricultural systems. *Science*, *362*(6417), eaav0294.

Pretty, J. N. (1997). The sustainable intensification of agriculture. *Natural Resources Forum*, *21*(4), 247–256.

Pretty, J., & Bharucha, Z. P. (2014). Sustainable intensification in agricultural systems. *Annals of Botany*, *114*(8), 1571–1596.

Robens, J. F., & Richard, J. L. (1992). Aflatoxins in animal and human health. *Reviews of Environmental Contamination and Toxicology*, *127*, 69–94.

Rockström, J., Williams, J., Daily, G., Noble, A., Matthews, N., Gordon, L., … de Fraiture, C. (2017). Sustainable intensification of agriculture for human prosperity and global sustainability. *Ambio*, *46*(1), 4–17.

Röling, N. G., & Jiggins, J. (1996). The ecological knowledge system. *2nd European symposium on rural and farming systems research: Technical and social systems approaches to sustainable rural development, Granada, Spain* (pp. 116–120).

Sinclair, F., & Coe, R. (2019). The options by context approach: A paradigm shift in agronomy. *Experimental Agriculture*, *55*(S1), 1–13.

Smith, A., Snapp, S., Chikowo, R., Thorne, P., Bekunda, M., & Glover, J. (2017). Measuring sustainable intensification in smallholder agroecosystems: A review. *Global Food Security*, *12*, 127–138.

Steinke, J., Achieng, J. A., Hammond, J., Kebede, S. S., Mengistu, D. K., Mgimiloko, M. G., … van Etten, J. (2019b). Household-specific targeting of agricultural advice via mobile phones: Feasibility of a minimum data approach for smallholder context. *Computers and Electronics in Agriculture*, *162*, 991–1000.

Steinke, J., Mgimiloko, M. G., Graef, F., Hammond, J., van Wijk, M. T., & van Etten, J. (2019a). Prioritizing options for multi-objective agricultural development through the positive deviance approach. *PLoS ONE*, *14*(2), e0212926.

Sulaiman V, R., Hall, A., Kalaivani, N. J., Dorai, K., & Reddy, T. V. (2012). Necessary, but not sufficient: Critiquing the role of information and communication technology in putting knowledge into use. *The Journal of Agricultural Education and Extension*, *18*(4), 331–346.

Šūmane, S., Kunda, I., Knickel, K., Strauss, A., Tisenkopfs, T., Rios, I., … Ashkenazy, A. (2018). Local and farmers’ knowledge matters! How integrating informal and formal knowledge enhances sustainable and resilient agriculture. *Journal of Rural Studies*, *59*, 232–241.

Taylor, M., & Bhasme, S. (2018). Model farmers, extension networks and the politics of agricultural knowledge transfer. *Journal of Rural Studies*, *64*, 1–10.

URT. (2013). *National agricultural policy*. Dar Es Salaam: MAFC.

URT. (2015). *Agricultural sector development strategy II, 2015/2016–2025/2026*. Dar Es Salaam: MAFC.

van Etten, J., Beza, E., Calderer, L., van Duijvendijk, K., Fadda, C., Fantahun, B., … Zimmerer, K. (2019). First experiences with a novel farmer citizen science approach: Crowdsourcing participatory variety selection through on-farm triadic comparisons of technologies (tricot). *Experimental Agriculture*, *55*(S1), 275–296.

Wyche, S., & Steinfield, C. (2016). Why don't farmers use cell phones to access market prices? Technology affordances and barriers to market information services adoption in rural Kenya. *Information Technology for Development*, *22*(2), 320–333.

Zoundji, G. C., Okry, F., Vodouhê, S. D., & Bentley, J. W. (2018). Towards sustainable vegetable growing with farmer learning videos in Benin. *International Journal of Agricultural Sustainability*, *16*(1), 54–63.